The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)

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The U. S. Navy has a need for the analysis and prediction of the atmosphere and the ocean. Routine military exercises can be profoundly affected by variations in the atmospheric temperature, relative humidity, and wind; and by variations in the ocean temperature, salinity, and currents. These variations can significantly affect tactical parameters, such as radar propagation, acoustics, and visibility, which can be critical to the success of military missions. Often, these variations occur across small space and time scales, making them difficult to observe and to predict.

The most consistent method to obtain analyses and predictions of the atmosphere and ocean is through the use of data assimilation and prediction systems that rely on sophisticated data quality control and analysis methods, and numerical prediction models. The use of such systems allows for the merging of observations from many different *in situ* and remotely-sensed sources with a background field provided by a numerical prediction model, into a four-dimensional description of the state of the atmosphere and/or ocean. The observations provide information about the current conditions while the background field provides information from observations taken at previous times by projecting them forward to the current analysis time. This process is important in order to maintain spatial and temporal consistency, and to allow the history of previous observations to be maintained in future analyses. In so doing, the model is allowed to generate useful information in data-void regions, based on the interpolation of the observations from adjacent areas and in relying on the dynamics and physics of the model to project this data forward in space and time. The performance of each of the components of the data assimilation system is critical to the overall performance of the entire system. The errors in the observations, in the analysis methods, and in the forecast model determine the quality of the final analyses.

Typically, data assimilation systems have been developed separately for the atmosphere and ocean. However, there is increasing evidence that suggests that the atmosphere and ocean data assimilation systems should be combined. It is clear that the atmosphere has a profound influence on the ocean. The atmosphere acts as the upper boundary condition for the ocean, and the surface atmospheric winds, temperature, precipitation, and radiation flux all play a strong role in forming and modulating the ocean circulation and thermohaline structure. There are indications that interaction with the ocean modifies the overlying atmosphere in important ways, as well. For example, recently Samelson et al. (2001) found that during coastal upwelling, the surface atmospheric temperature was cooled by one to five degrees on a 12–24 hour timescale by contact with the cooler ocean waters upwelled from depth. Also, Chelton et al. (2001) reported evidence of significant alterations in the observed equatorial surface wind stress field due to coupling between the atmospheric boundary layer and the underlying sea surface temperature. To fully

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account for these observed interactions as well as to anticipate the discovery of a host of other ways in which the ocean and atmosphere modify each other, NRL has undertaken the development of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS; Hodur, 1997). The goal of this modeling project is to gain predictive skill in simulating the ocean and atmosphere at high resolution on time-scales of hours to several days. Significant questions exist as to how tightly coupled the atmosphere and ocean data assimilation systems must be, and over what types of atmospheric and ocean conditions this coupling is important. The purpose of this paper is to provide a description of the status of COAMPS and present recent results.

COAMPS Description

Atmospheric Component

While COAMPS represents an air-ocean coupled system, until recently much of the work focused on the development, testing, and the operational implementation of the four principal components of the COAMPS atmospheric data assimilation system. The first component is the quality control of observations, in which observational data from many sources (e.g. radiosondes, aircraft, satellite, ships) are screened for errors, redundancy, consistency with the previous forecast, etc. (Baker, 1992). The second component is the analysis, in which the irregularly-spaced, quality controlled data are interpolated to the model's regularly-spaced grid. The interpolation method used by COAMPS is based on the multivariate optimum interpolation method (MVOI; Lorenc, 1986). In the third component, model initialization, the analyzed fields are adjusted to conform to one or more dynamic and/or physical constraints. Finally, the fourth component is the numerical forecast model, which integrates the initialized fields forward in time, using some approximate formulation of the primitive equations.

A great deal of flexibility has been built into COAMPS. First, the COAMPS grid can be set to any domain size and grid spacing at runtime, within the constraints of the computer system being used. Second, the grid can be located anywhere over the world, using one of 5 different map projections: polar stereographic, Mercator, Lambert conformal, spherical, or cartesian. Third, the system can be initialized with real- or idealized-data. Fourth, the model uses nested grids. The grid spacing is reduced by a factor of 3 between each nest. In this manner, the COAMPS grid can telescope down to resolutions of less than 10 km for areas in which high resolution is a necessity. Any number of nests can be defined at runtime. Fifth, a variety of lateral boundary conditions are available, supporting both real- and idealized-data experiments. Sixth, a single configuration managed version of COAMPS is used for all applications.

The atmospheric forecast model in COAMPS uses the nonhydrostatic form of the primitive equations as described in Klemp and Wilhelmson (1978). The non-hydrostatic form of the equations is necessary for modeling systems using a horizontal resolution less than approximately 10 km. For these resolutions, the vertical acceleration may become important, such as in convective systems or strong flow around steep topography. The COAMPS equations are solved on a staggered C-grid. COAMPS contains an advanced moist physics parameterization (Rutledge and Hobbs, 1983), that is used in lieu of convective parameterization below 10 km grid spacing. This moist physics parameterization contains explicit equations for water vapor, cloud droplets, raindrops, ice crystals, and snowflakes. In addition, the COAMPS atmospheric model uses state of the art parameterizations for boundary layer processes and radiation. A more complete description of the atmospheric components of COAMPS is given in Hodur (1997).

The atmospheric portion of COAMPS has been run operationally at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) since July 1998. It is currently run for eight separate areas, covering Europe, portions of Asia, the continental U. S., and surrounding waters. Additional areas are run as needed to support Navy activities throughout the world. The European and one of the Asian areas use triply-nested grids with resolutions of 81, 27, and 9 km; the others use doubly-nested grids at 81 and 27 km. All COAMPS areas currently use 30 vertical levels, with the model top at approximately 34 km. Forecasts are made using a 6 or 12-hour data assimilation cycle, depending on the region. Production forecasts are made twice a day. These extend to 24 hours on the 9 km grids, and to either 48 or 72 hours on the 81 and 27 km grids. Model output is interpolated from the 27 and 9 km grids to spherical grids with 0.2 and 0.1 resolution, respectively, and to constant pressure or height levels, as appropriate. Thousands of fields are produced from each model run and distributed to Navy and other users around the world. Graphical displays of selected products for the U. S. and surrounding waters may be viewed at http://www.fnmoc.navy.mil/PUBLIC/WXMAP/. Model output fields can be obtained in near-real time from http://www.usgodae.fnmoc.navy.mil/ via several common protocols.

Ocean Component

The ocean analysis component of COAMPS is a fully 3-dimensional oceanographic implementation of the multivariate optimum interpolation (MVOI) algorithm that is used in the COAMPS atmospheric analysis component. The theoretical basis of the multivariate method is described in Lorenc (1981) and Daley (1991). The ocean analysis variables are temperature, salinity, geopotential, and the u-v velocity components. Geopotential observations are calculated from observations of temperature and salinity assuming a level of no motion. The multivariate correlations compute geostrophically balanced increments of velocity from

the analyzed increments of geopotential. In this way, adjustments to the ocean's mass field are correlated with adjustments to the ocean's flow field. The geostrophic coupling is relaxed near the equator and in shallow water where friction terms dominate the flow. The COAMPS ocean analysis component is executed in a sequential incremental update cycle, and a short-term model forecast (or previous analysis) provides the analysis background field.

All observed data are subject to quality control (QC) procedures prior to assimilation. The primary purpose of the QC system is to identify observations that are obviously in error, as well as the more difficult process of identifying measurements that fall within valid and reasonable ranges, but are erroneous. A secondary use of the QC system is the creation and maintenance of an analysis-forecast increment database for use in the *a posteriori* computation of the optimum interpolation statistical parameters. QC procedures common to all data types include land/sea boundary checks and background field checks (previous analysis, forecast, climatology). QC procedures unique to different data types include: location (speed) test for drifting buoy and surface ship observations; instrumentation error checks for expendable bathythermographs (XBTs) and profiling PALACE floats; sensor drift for fixed and drifting buoys; and large-scale bias detection for satellite retrievals of sea surface temperature (SST). The need for quality control is fundamental in the analysis system; erroneous data can cause an incorrect analysis, while rejecting extreme data can miss important events. The decisions made at the quality control step are likely to affect the success or failure of the entire ocean analysis/forecast system.

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The COAMPS ocean analysis can also be used to construct 2D ocean fields of SST and sea ice concentration. These 2D fields are used as the lower boundary conditions in the atmospheric forecast model. SST analyses are created using both satellite SST retrievals and *in situ* measures of SST from surface ship and fixed and drifting buoy data. Sea ice concentration is analyzed using DMSP SSM/I retrievals of ice concentration. SST and sea ice are analyzed simultaneously and are cross validated by (1) setting positive sea ice concentration retrievals to 0% ice when SST exceeds 1°C, and (2) inserting supplemental SST observations at the freezing point of sea water into the analysis when sea ice concentration exceeds 55%. This is the only part of the ocean analysis that is currently in operational use at FNMOC.

The greatest difficulty of any eddy resolving ocean data assimilation system is the lack of synoptic real-time data at depth. On a global basis the daily accumulation of XBT data routinely available is approximately 250 reports. To supplement the sparse subsurface thermal observations, the COAMPS ocean analysis system generates temperature profiles from the Modular Ocean Data Assimilation System (MODAS) database. The MODAS database contains coefficients that are used to infer subsurface temperature structure from satellite altimeter sea surface height (SSH) observations and analyzed SST. The synthetic profiles are appended to the real-time observations and assimilated in the same way as any other observation, but with unique error characteristics specified. The errors of the synthetic profiles are dependent both on the accuracy of the SST and SSH predictor fields and on the magnitude of the correlation of the subsurface temperature structure to SST and SSH. The synthetic profile errors vary in both space and time. In the COAMPS ocean analysis system, every temperature observation must have a companion salinity observation. Since virtually no salinity observations are available in real-time, salinity is computed from temperature using climatologically based temperature-salinity relationships in the MODAS database.

The COAMPS ocean analysis system supports the same map projections (Mercator, Lambert Conformal, Polar Stereographic, Spherical) as the COAMPS atmospheric system. In addition, the ocean analysis can be run on a nested grid structure at various grid resolutions producing multi-scale analyses. The update cycle of the COAMPS ocean analysis can be set independently of the atmospheric analysis update cycle, and post-time analyses can be run to process delayed-mode observations. Timely receipt of ocean observations is an important issue for a real-time system, and particularly so when the ocean forecast model is run in a coupled mode with the atmospheric forecast model. The COAMPS ocean analysis system has been designed to handle the inevitable delays in the receiving and processing of observations at the production center.

The COAMPS ocean model is the Navy Coastal Ocean Model (NCOM) developed by Martin (2000). NCOM is designed to offer the user a range of numerical choices in terms of parameterizations, numerical differencing, and vertical grid structure. NCOM is based on the hydrostatic primitive equations, and has prognostic variables for the ocean currents, temperature, salinity, and surface height. An implicit formulation is used for the barotropic component. The equations are solved on the staggered C grid. One special aspect of NCOM is that it uses a hybrid vertical coordinate system. In this system, one can use all sigma-levels, all z-levels, or a combination of the sigma-levels for the upper ocean and z-levels below. Advection can be treated with second-order centered, or third-order upwind finite differencing. Options for boundary layer mixing include Mellor–Yamada 2.0 and Mellor–

Table 1

COAMPS reanalysis areas, resolutions of grids, starting date of reanalyses, and ending date that reanalyses have been run through. Multiple numbers for resolutions refer to the grid spacing in each mesh used in a nested grid application.

Area	Resolutions (km)	Start Date	Through
Mediterranean Sea	81/27	1 Oct 98	30 Sept 00
Mediterranean Sea	36/12	1 Oct 99	30 Nov 99
Eastern Pacific	81/27/9	1 Oct 98	30 Sept 00
Baltic Sea	81/27/9	1 Nov 99	31 Jan 00
Adriatic Sea	36/12/4	1 Oct 00	30 Nov 00

Yamada 2.5 schemes. The model also includes options for treating open boundaries using radiation schemes that have been successful in numerical models in the past.

A flux coupler has been developed to couple the COAMPS atmosphere and ocean models through the exchange of surface fluxes of heat, momentum, moisture, and radiation across the air-water interface, as well as to include the effects of precipitation falling into the ocean. Since the atmospheric and ocean models are expected to have different resolutions for many applications (and perhaps different grid projections, as well), the flux coupler has been designed to interpolate fields between the atmospheric and ocean grids to account for these differences. Special care is taken to ensure consistency of the forcing fields at the land/sea boundary.

Results

Atmospheric Reanalyses

The success of an ocean model forecast is limited by the accuracy of the surface momentum and heat flux fields supplied by the atmospheric model. Unfortunately, features with relatively small spatial and temporal scales often characterize these atmospheric fields. This is most pronounced near coastlines, where strong diurnal temperature oscillations can cause rapid wind changes and where interactions of the wind with steep topography can force strong local wind patterns. This implies that the atmospheric forcing must come from high-resolution analyses and/or forecasts that can resolve such features. In this project, we are generating high spatial and temporal resolution fields to force the COAMPS ocean model by running the COAMPS atmospheric data assimilation system for extended time periods over regions of interest. We are currently focusing on four different areas for our atmospheric reanalyses: the Mediterranean Sea, the eastern Pacific, the Baltic Sea, and the Adriatic Sea. Details of these areas are presented in Table 1. Note that two different sets of reanalyses are being done over the Mediterranean Sea, with the difference in the two runs being the horizontal resolutions of the grids.

The COAMPS reanalyses are all produced using a 12-hour incremental data assimilation cycle. The first analysis for each area uses the analysis fields valid at the starting time from the Navy Operational Global Atmospheric Prediction System (NOGAPS) for the first guess, and performs a 3-D MVOI analysis using all available observations for that time. All subsequent analyses for that particular area use the 12 hour COAMPS forecast fields for each nest generated from the previous analysis time as the first guess fields. Also at each analysis time, a 2D OI analysis of the SST is generated for each COAMPS grid nest. Following each analysis, a 24-hour forecast is generated for each nest. A sample of the SST analyses for the three nests over the eastern Pacific are shown in Figure 1. During each forecast, selected fields (Table 2) are output on an hourly basis to serve as the upper boundary conditions for the COAMPS ocean model.

The significance of the resolution of COAMPS on the wind fields in an area such as the Mediterranean is seen in Figure 2. The Mediterranean is typically dominated by many local winds (e.g. Mistral, Levante, Etesian). The Mistral is formed in the Gulf of Lion by the channeling of the flow between the Pyrennes on the border of France and Spain, and the Alps in northern Italy. Using an 81 km grid, the average wind for the month of November 1999 in the Gulf of Lion is approximately 5 m/s, while it is approximately 9 m/s in the 27 km grid. Independent verification of the Mistral for individual cases (not shown) indicates that the 27 km grid represents the maximum winds in the Mistral better than the 81 km grid. The strength of the Mistral and the other local wind regimes in the area around the Mediterranean, and the associated increase in surface

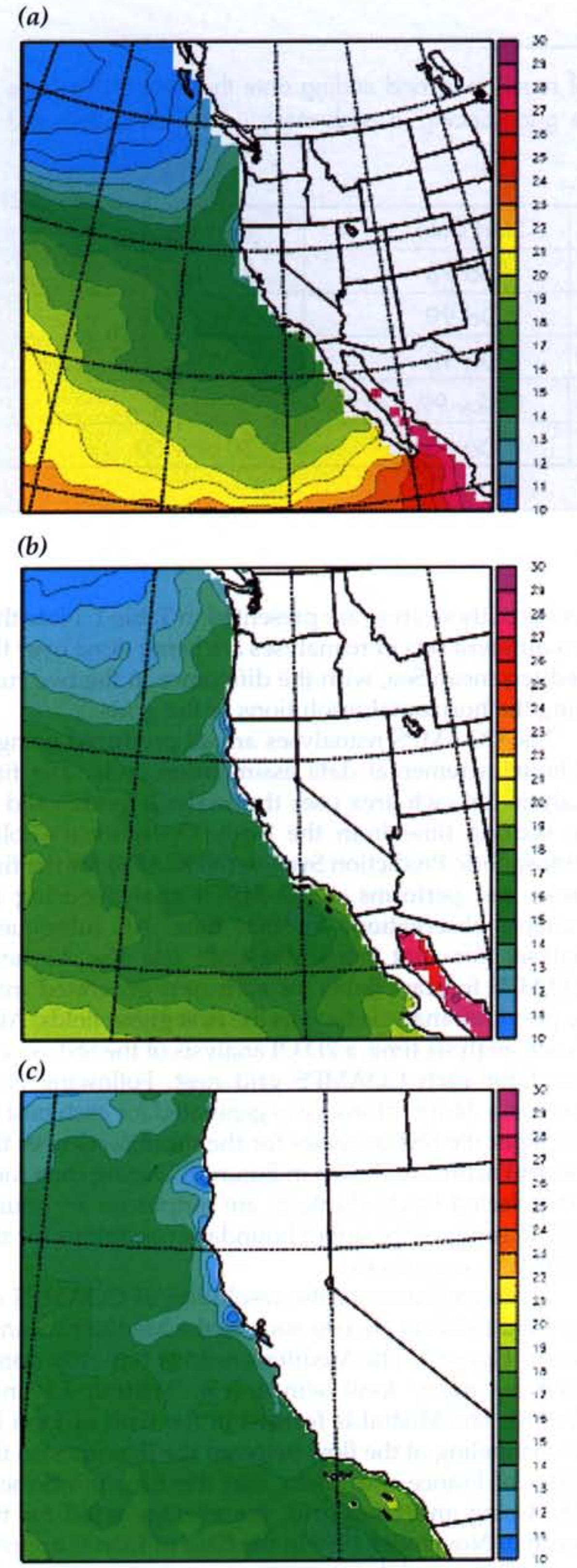

*Figure 1. COAMPS sea surface temperature analyses using 2-dimensional optimum interpolation analysis at 0000 UTC 1 July 1999 for **a)** 81 km grid, **b)** 27 km nest, and **c)** 9 km nest.*

Table 2

List of COAMPS fields and associated levels output hourly for each reanalysis area.

Field	Level
Pressure	Mean sea level
u-component of wind	10 m
v-component of wind	10 m
Air temperature	2 m
Relative humidity	2 m
Total precipitation	Surface
Sensible heat flux	Surface
Latent heat flux	Surface
Total radiative flux	Surface
Solar radiative flux	Surface
Total wind stress	Surface
u-component of stress	Surface
v-component of stress	Surface

stress, is expected to play a large role in the circulation and thermohaline structure of the Mediterranean Sea.

Air-Ocean Coupling: Ocean Spin-up

Initial tests of air-ocean coupling with COAMPS are focused on the Mediterranean Sea. This body of water was chosen for a number of reasons. First, it is an area that routinely exhibits many small-scale features both in the atmosphere and in the ocean that can be adequately represented only by a high-resolution system such as COAMPS. Second, analyses and forecasts in the area around the Mediterranean Sea for both the atmosphere and ocean are very important for the missions that the U.S. Navy conducts in this area. Finally, the Mediterranean Sea is a nearly enclosed basin, meaning it can be run without global ocean fields for lateral boundary conditions.

The first test with NCOM was to perform a multi-year spin-up over the Mediterranean Sea. This spin-up uses the hourly fields from the COAMPS atmospheric reanalyses described above to force NCOM. For this experiment, NCOM used a horizontal resolution of 9 km and 30 vertical levels (5 sigma-levels at the top, 25 z-levels below). An inflow of 1.0 Sverdrups was prescribed at the Strait of Gibraltar with a return flow of the same magnitude in the bottom-most layers. NCOM was integrated for over two years, using the COAMPS reanalysis fields from October 1998 through September 1999 for each year of the multi-year spin-up. After this time, it was assumed that the model reached a steady state, based on the time series of the domain-averaged kinetic energy (Figure 3).

The preliminary analysis presented here is focused

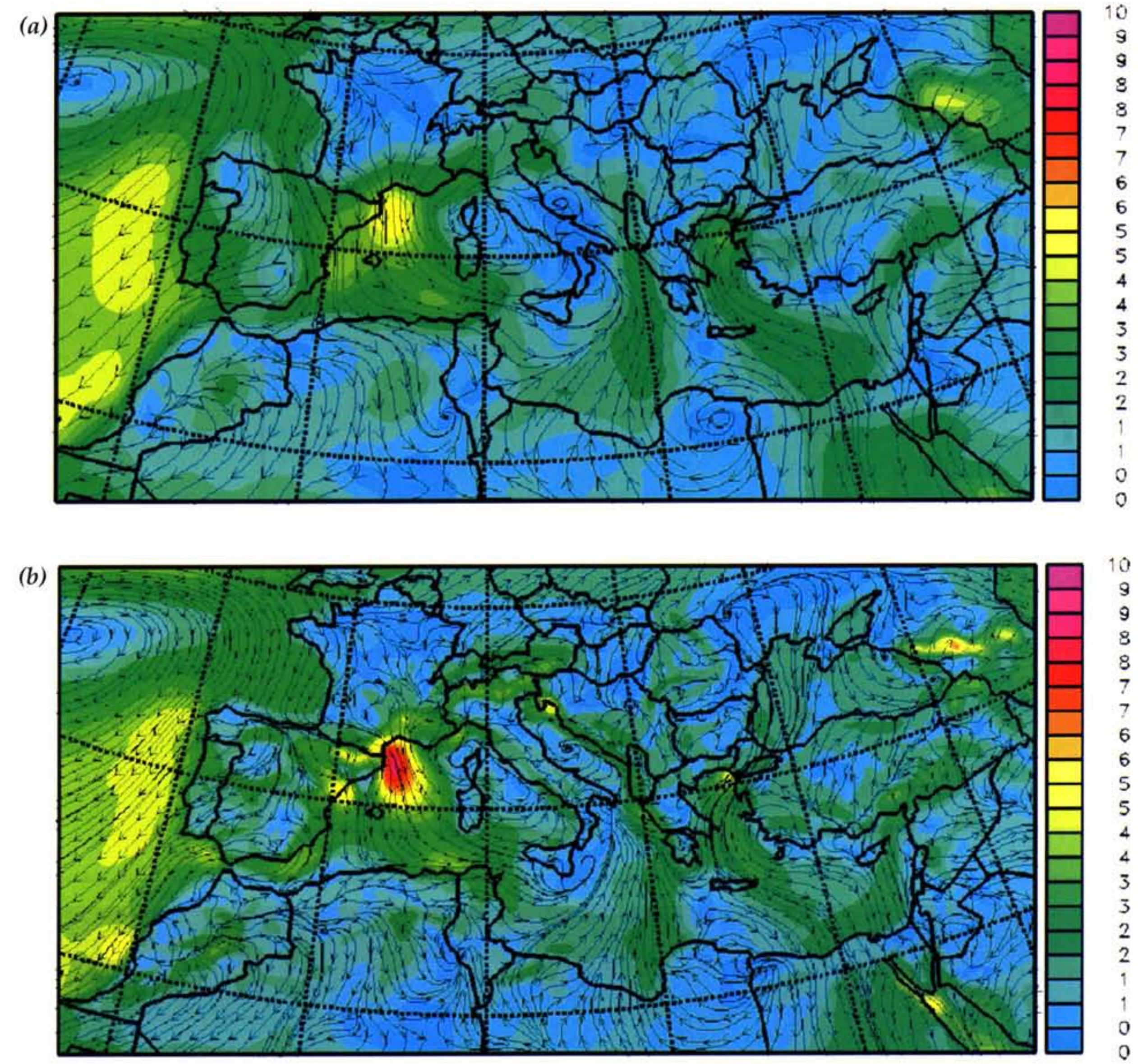

Figure 2. *Average 10 m wind speed (m/s) and streamlines from COAMPS reanalyses over the Mediterranean area for November 1999 for **a)** 81 km grid, and **b)** 27 km grid. Winds are averaged for forecast times of 1–12 hours, in hourly intervals. In **a)**, only that portion of the 81 km grid that is coincident with the 27 km grid is shown.*

on the second year of this spin-up. Using the flux coupler with hourly COAMPS forcing, NCOM is able to simulate many observed features of the general circulation of the Mediterranean Sea, such as sub-basin scale gyres and intense coastal boundary currents. The mean surface height of the Mediterranean Sea generated from the second year of our spin-up run is shown in Figure 4. Cyclonic (i.e. counterclockwise) motion dominates the northern part and anticyclonic motion (i.e. clockwise) dominates the southern part of the Mediterranean Sea. Two anticyclonic gyres are formed in the Alboran Sea with the eastern one constituting the Almeria-Oran front, which is a strong density gradient between the inflowing Atlantic water and the resident water of the Mediterranean. The prominent jet-like currents generated in the simulation include: the Algerian current flowing along the Algerian coast, the Atlantic Ionian Stream, the Mid-Mediterranean Jet, and the Asia minor current in the east. Our simulations also include cyclonic gyres (Lions, Tyrrhenian, Cretan, and Rhodes gyres) and the anticyclonic gyres (Pelops, Mersa-Matruh, and Shikmona gyres) that are consistent with observations made in the Mediterranean, such as those reported by Pinardi and Masetti (2000). In addition, there is evidence of three cyclonic gyres in the Adriatic Sea.

Air-Ocean Coupling: Data Assimilation

The ocean data assimilation system relies on a tight

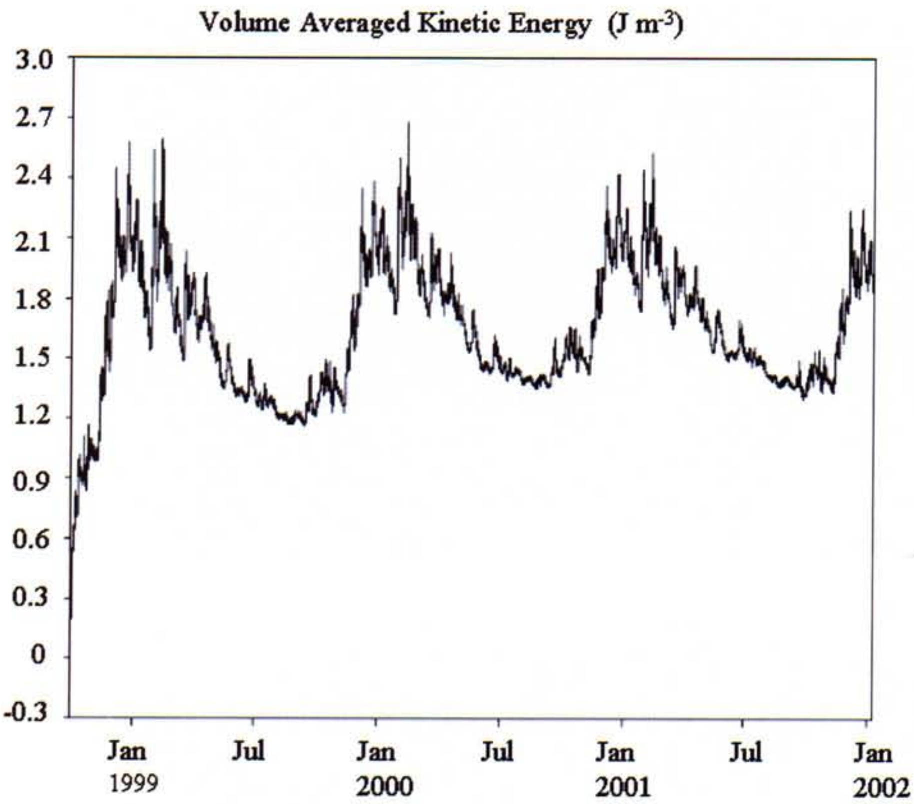

Figure 3. Volume averaged kinetic energy for NCOM spin-up.

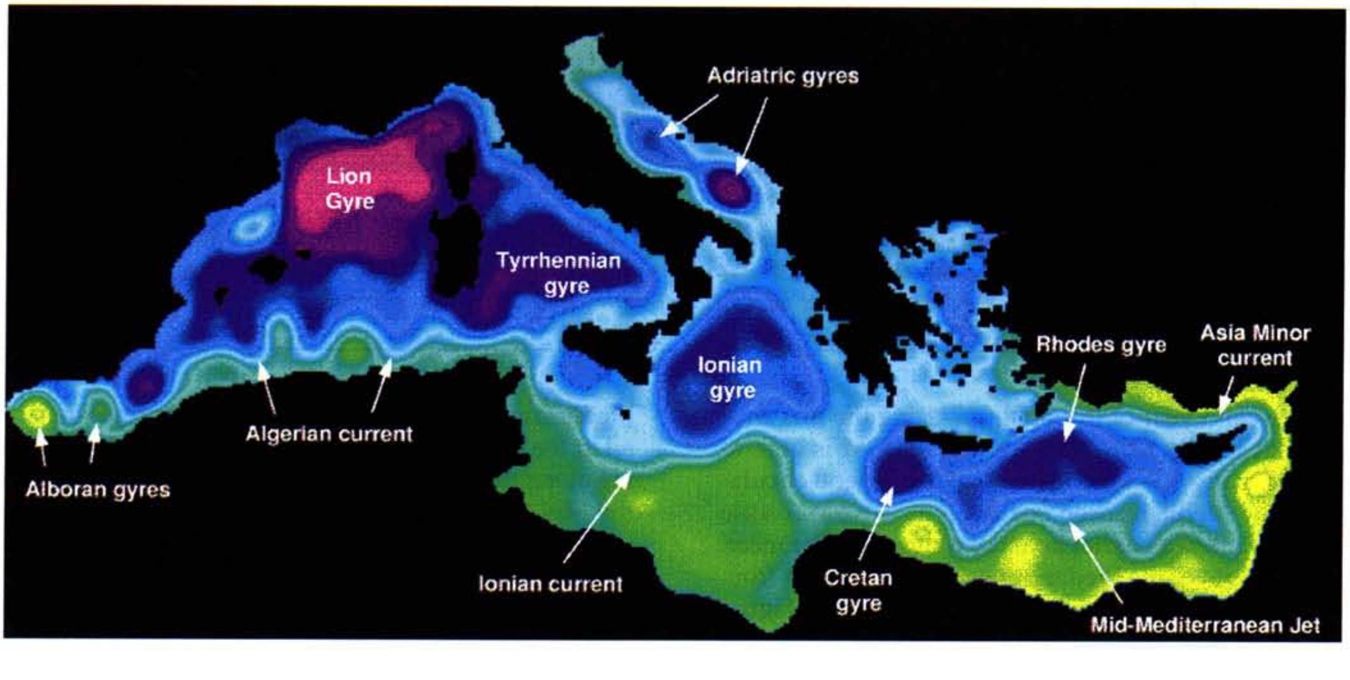

Figure 4. Annual mean surface elevation (5 cm interval between colors) for the second year of NCOM spin-up with general features of the circulation. The highest surface elevations are colored in yellow and the lowest surface elevations are colored in blue/purple.

coupling between the ocean MVOI analysis and the NCOM ocean forecast model. To achieve this, both components share the same high-resolution bathymetry and land/sea fields on a grid with the same horizontal and vertical dimensions. Current tests are for the Mediterranean Sea using a 6 km horizontal resolution on a Lambert conformal grid projection with 40 vertical levels. The 40 ocean levels in the ocean model have a distribution of 15 vertical sigma levels in the upper 100 m, with 25 z-levels below. The minimum ocean depth is set at 5 m.

The system is initialized from an ocean MVOI analysis that uses the U.S. Navy Generalized Digital Environmental Model (GDEM; Teague et al., 1990) temperature and salinity climatology as first guess fields and assimilates observations with an expanded data time window. These "cold start" fields are interpolated from the MVOI z-levels to the sigma/z-levels of NCOM. A static stability test is performed, and the temperature and salinity are adjusted to achieve neutral buoyancy, if required. NCOM is then run in a prognostic mode using the previous 5 days of forcing (i.e. 26–30 September) from the 27 km COAMPS. These fields, valid at 0000 UTC 1 October 1999, represent the starting conditions for all subsequent analysis and data assimilation experiments. In the first experiment (referred to as "persistence"), an ocean MVOI analysis is constructed at 12 hour intervals using the previous analysis for the first guess fields. Analyses are constructed every 12 hours for the entire month of October 1999 using this procedure. In the second experiment (referred to as "data assimilation"), MVOI analyses are again performed at 12 hour intervals, but use the 12-hour NCOM forecast temperature, salinity, and velocity fields as the first guess fields. A 4 day ocean forecast is produced at each analysis update time, during which the upper boundary of NCOM is forced with fields from the 27 km COAMPS reanalysis. In the third experiment (referred to as "forecast"), NCOM is integrated forward from the 1 October 1999 initial conditions described above, through the entire month of October 1999, without any further assimilation of data other than forcing at the upper boundary by fields from the 27 km COAMPS reanalyses. A series of expendable bathythermograph (XBT) transects, taken as part of the Mediterranean Forecast System Pilot Program (MFSPP), are used as independent observations to assess the skill of the system (Figure 5). All MFSPP XBT observations from October 1999 are used in the evaluation of forecast skill. All forecast and analysis fields used in the verification statistics are valid at the MFSPP XBT observation time and sampling depth.

Figure 6 shows the RMS and mean bias errors for the persistence experiment, for different forecast times (i.e. 12, 24, and 36 hour forecasts) in the data assimilation experiment, and for the forecast experiment; and the total observation count. The far right panel in Figure 6 shows that the majority of the MFSPP XBT drops only sampled the upper 100 m of the water column. RMS and mean bias errors are greatest near the depth of the mixed layer (~50 m depth) in all runs, and the errors increase with forecast period. The forecast experiment exhibits smaller errors at the depth of the mixed layer, but larger errors within the mixed layer itself, defined here to be depths shallower than 50 m. The persistence experiment exhibits smaller errors than the 12, 24, and 36 hour NCOM forecasts from the data assimilation run. This result suggests the need for an initialization step in the ocean data assimilation cycle, as is done in the COAMPS atmospheric component.

Figures 7 and 8 give cross-sections of the two western-most legs of the MFSPP XBT drops. The cross sections are plotted from north to south. Leg 2 was sampled from 3–4 Oct and leg 3 was sampled from 17–21

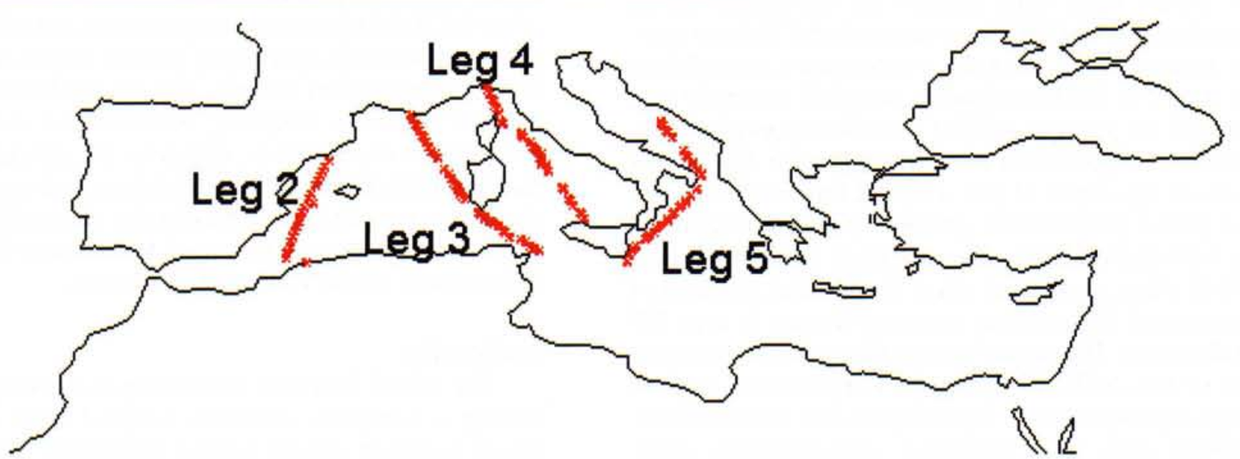

Figure 5. *Mediterranean Forecast System Pilot Project XBT drops during October 1999. The XBT samples were made along sections which, from west to east, are referred to as Leg 2, Leg 3, Leg 4, and Leg 5.*

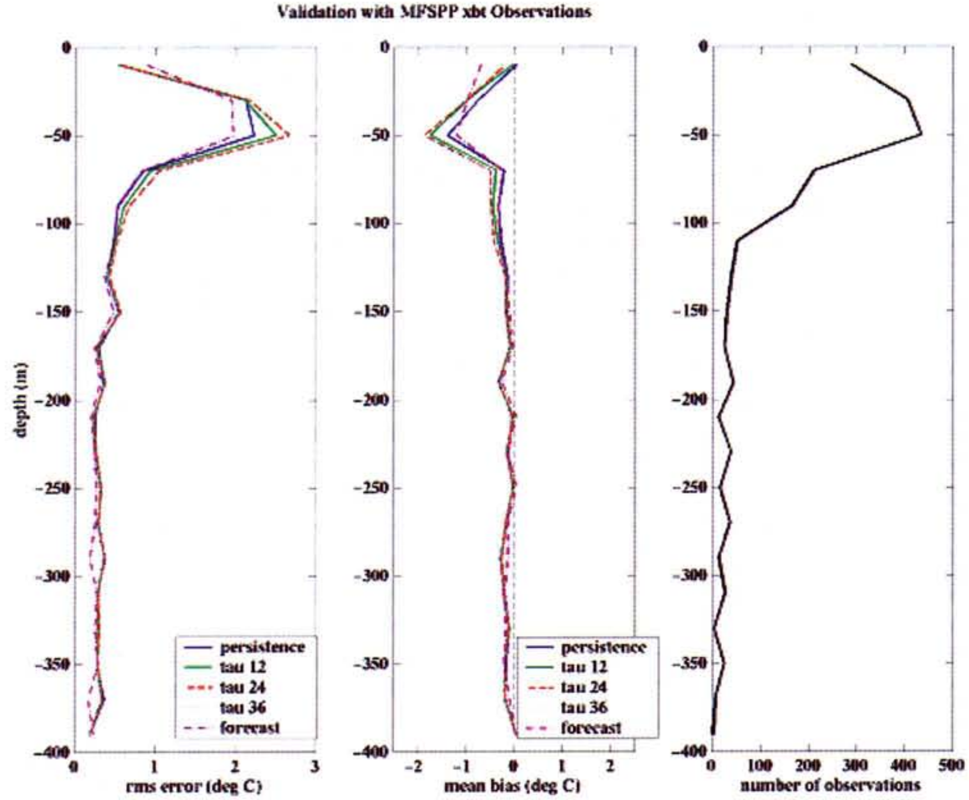

Figure 6. RMS and mean bias errors and observation count for MFSPP XBT observations during October 1999. Note that the XBT data are reported at inflection point levels in the vertical and, as a result, the data have been binned into 20-m depth intervals for computation of the average error statistics. For the rms and bias errors, the solid blue line represents results from MVOI analysis fields created using previous analysis as the first-guess, the solid green line represents 12 hour NCOM forecasts from a 12 hour incremental data assimilation run, the long-dashed red line represents 24 hour NCOM forecasts from a 12 hour incremental data assimilation run, the dotted green line represents 36 hour NCOM forecasts from a 12 hour incremental data assimilation run, and the purple dash-dot line represents NCOM forecast started at 1 October 1999 that did not assimilate observations during the month of October.

Oct. Below each cross section are difference charts between observed XBT temperatures and 12-hour forecast temperatures from the cycling data assimilation run. Leg 2 is the more evenly sampled, synoptic section, and the 12-hour NCOM forecast shows good prediction of near-surface temperatures with the largest errors at the depth of the seasonal thermocline when the vertical temperature gradient is strong (Figure 7). Leg 3 prediction errors are very large when the mixed layer is deep, and again when the vertical gradient of the seasonal thermocline is strong (Figure 8, near 297 km distance). This result is most likely due to assimilation of the MODAS synthetic temperature profiles, which represent mixed layer depths and seasonal thermoclines only in a statistical, climatological sense. Current research is directed at investigating the methods for the generation and application of MODAS synthetics and their role in determining the forecast skill in the Mediterranean Sea. The mean cold bias in the upper 100 m in all of the simulations (middle panel, Figure 6) may in part be attributed to the marginal skill of the MODAS synthetics, as generated and assimilated in this experiment, but it may also be due to a number of other factors that include, but are not limited to the lack of two-way coupling between the ocean and atmosphere components, errors in the physical parameterizations in both the atmosphere and ocean models, and errors and/or biases in the atmospheric forcing. Future efforts will be aimed at assessing the source of the ocean model RMS and bias errors.

Summary

The Naval Research Laboratory is developing and testing a complete air-ocean coupled data assimilation/prediction system named COAMPS. The atmospheric data assimilation component of COAMPS has been in operational use at FNMOC since 1998, and it provides atmospheric analyses and forecasts up to 72 hours ahead for 8 different geographical locations every 12 hours. These operational COAMPS areas use

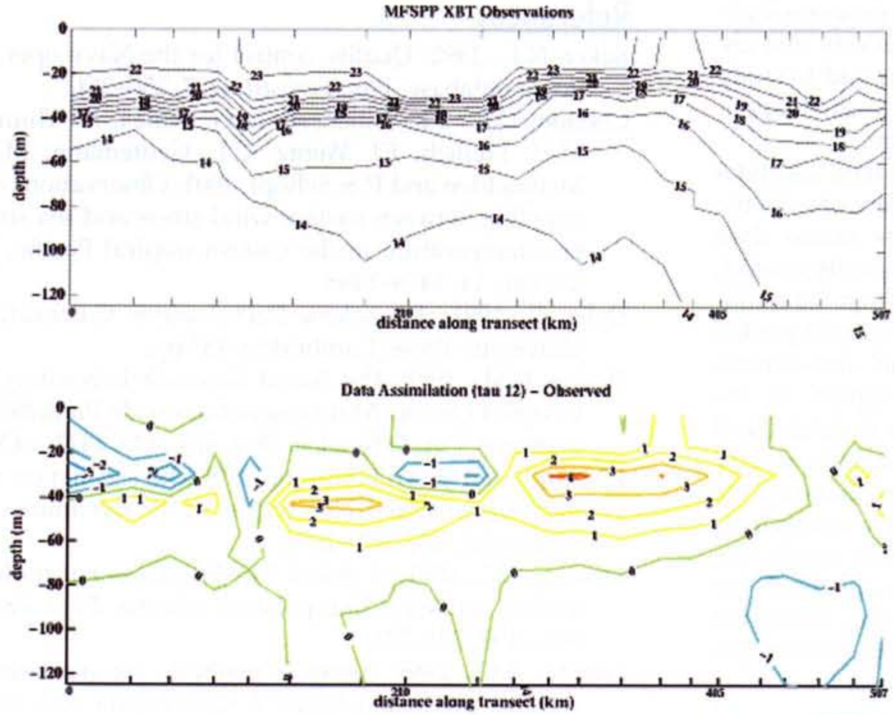

Figure 7. Cross-sections that shows XBT observations of temperature °C, ***(top)*** and the differences between NCOM forecasts and independent XBT observations along leg 2 in the western Mediterranean ***(bottom)***. Each XBT observation is represented by a tick mark along the x-axis. Since each of the XBTs along this path was taken at different times, the NCOM forecast field closest to each XBT was used to compare with each XBT.

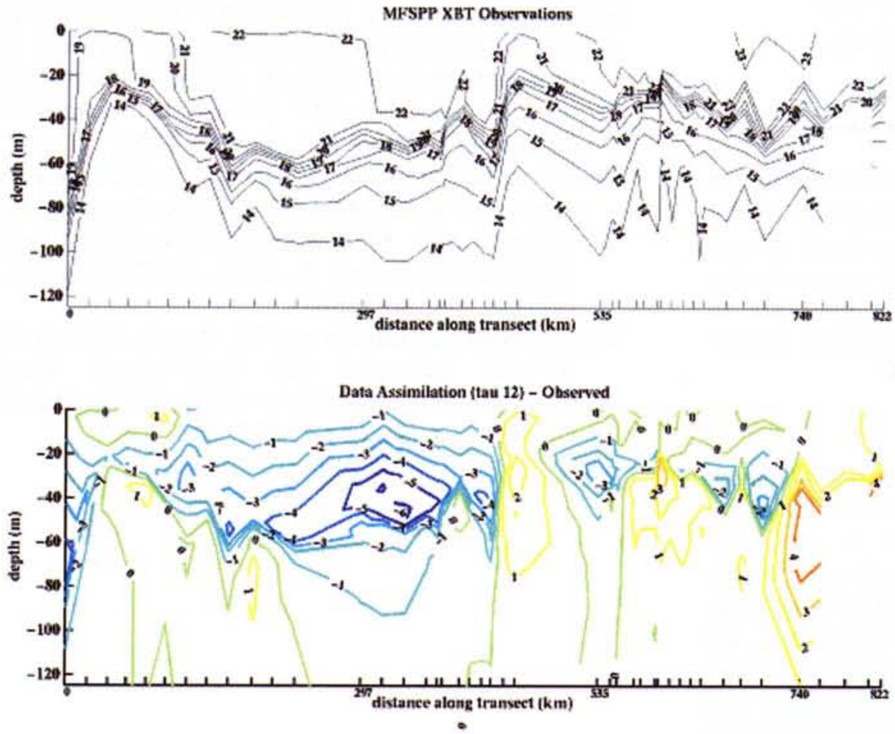

Figure 8. Cross section of MFSPP Leg 3 XBT drops ***(top)*** and difference chart between observed temperatures and 12-hour forecast temperatures from cycling ocean data assimilation run ***(bottom)***. Leg 3 was observed from 17-21 October 1999. The tick marks along the horizontal axis show the locations of the XBT drops. The temperatures and differences have been linearly interpolated between the XBT observation locations.

grid intervals down to 9 km. The operational COAMPS fields are used to provide weather guidance to Navy forecasters and for input to tactical application programs. COAMPS has also been used to generate high-resolution reanalyses for multi-year periods that are used to drive limited-area ocean models and to study the forecast skill of COAMPS. In some research applications, the grid interval is less than 1 km.

NRL is now developing the ocean data assimilation component of COAMPS and coupling this to the existing atmospheric component. The ocean data assimilation component includes data quality control, a 3-dimensional analysis capability through the multivariate optimum interpolation technique, and a prediction capability through a hydrostatic, free-surface ocean model, NCOM. NCOM is coupled to the COAMPS atmospheric model through a generalized flux coupler. The flux coupler allows for different grid projections and different grid resolutions between the atmospheric and ocean grids. Preliminary results indicate that NCOM, when run in a forecast mode, can simulate many of the observed features of the Mediterranean Sea using high-resolution COAMPS atmospheric forcing. The results also indicate that the use of an incremental data assimilation technique is a powerful tool for combining the forecast skill of the ocean model with advanced analysis methods to construct accurate analysis and forecast ocean fields. Future research efforts will address methods to improve our data assimilation techniques and to validate the performance of the system.

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